Note on the Sensibility of the Ear to the Direction of Explosive Sounds.

By A. Mallock, F.R.S.

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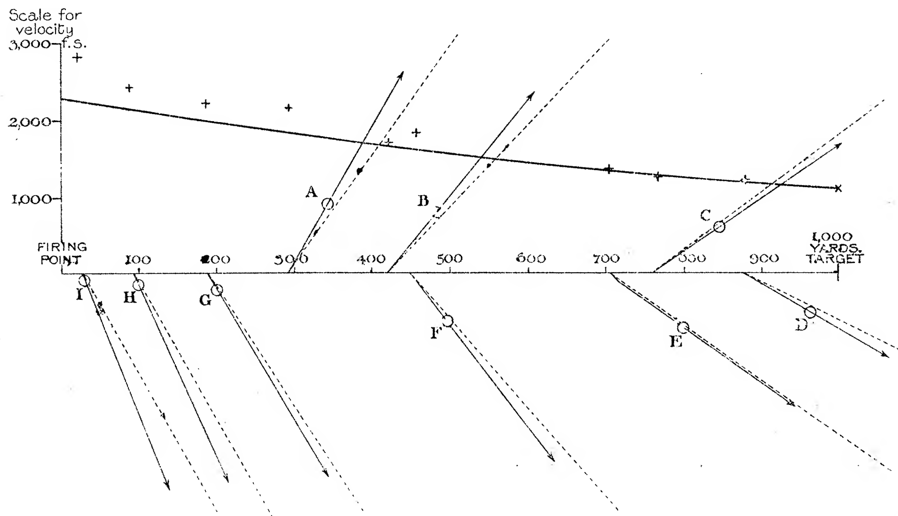
Soon after the introduction of modern rifles, which give their projectiles a velocity much higher than that of sound, I noticed that when standing in a position in front of the gun and not far from the line of fire, the sound seemed to come, not from the firing point, but from some point considerably in advance of the gun. The natural explanation seemed to be that the sound thus heard was not that of the explosion itself, but was caused by the wave-surface, which is generated in the air by the projectile, moving at a velocity higher than sound. In 1898 I made some observations at the ranges at Browndown to see if the apparent directions agreed with this supposition. A large range like Browndown, however, at which many parties are firing at the same time, was not a very good place for such observations, but in the present year I have again made similar experiments under much more favourable circumstances. It is clear (if the source of the sound is due to the wave caused by the projectile) that the apparent direction of the sound will be the normal to the wave-surface, and that if the direction of this normal is known, the velocity of the projectile, at the time that that particular portion of the wave-surface was generated which ultimately reaches the observer, can be calculated.

I now record these observations, not as giving a practical method of ascertaining the velocity of projectiles, but as showing that the ear can distinguish with considerable accuracy the direction of a sound which consists, not of a train of waves, but, at most, of two waves only. The figure gives the plan of the range and the stations at which the observations were made.

The arrows through these points show the direction of the sound as judged by ear. Each arrow is the mean of eight observations which rarely differed among themselves by more than two or three degrees.

That portion of the wave-surface which passes the observer at any station was generated at the point where the apparent direction of the sound cuts the line of fire, and since the trace of the wave on the trajectory necessarily has the velocity of the projectile at the place where it was formed and moves along the normal with the ordinary velocity of sound, it is plain that at those points the velocity of the bullet is the velocity of sound ÷ the sine of the angle which the tangent to the wave-surface makes with the trajectory.

The spots, +, show the velocities thus computed, and the full curve gives the actual velocity, as determined by firing, at various ranges up to 1000 yards, into a ballistic pendulum.



The arrows show the apparent direction of the sound at the stations A B C . . .

The dotted lines are the normals to the wave-surface, calculated from the known velocity of the projectile.

The full curve is the velocity of the projectile, obtained from experiments with the ballistic pendulum.

The spots, +, are the velocities of the projectile, as deduced from the observed direction of the sound.

The method by which the observations of the direction of the sound were made rendered it almost impossible for any bias on the part of the observer to affect the result.

At each station a piece of paper fixed to a drawing board was placed on the ground and a line ruled on it was directed to the firing point. At each shot the observer determined in his own mind what point in the horizon the sound seemed to come from (this could be located by reference to some distant tree or other object), and a line was then drawn on the paper in that direction.

After all the observations had been completed a plan of the range was made from the 25-inch Ordnance Map and the positions of the observing stations were marked. The observed angles between the direction of the sound and the line joining the station with the firing point were then laid off, and thus the angles between the direction of the sound and the line of fire were found.

The agreement of the values of the velocities thus obtained with the true velocities shows the degree of accuracy with which the direction of the sound was estimated. In this case the difference between the true and observed directions was seldom more than a few degrees and was generally in one direction.

A sound which is caused by the detached waves, such as those which accompany a bullet, can scarcely be said to have a pitch, but the wave-length is certainly small compared with the distance between the ears, and is indeed comparable with the dimensions of the bullet itself. It would seem, therefore, that the ears can determine the direction of a sound, not only by difference of phase, but by the actual difference in the times at which a single pulse reaches them.

It may be mentioned that the difficulty in determining the apparent direction of the sound increased considerably as the observer approached the firing point, for there the noise of the actual explosion became comparable with that caused by the bullet. At a distance of 500 yards the noise of the explosion was inconsiderable and at 1000 yards almost inaudible.